Sediment Acoustics

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LONG-TERM GOAL

The long-term goal of my work in sediment acoustics is to develop a physically meaningful model to describe geoacoustic wave propagation in marine sediments on the basis of a set of primitive physical variables.

OBJECTIVES

The principal scientific objective of my work has been to develop a mathematical model that is able to predict wave velocity and attenuation in the sediments found near the seafloor. Specifically, the model has been designed to accept as input parameters certain fundamental primitive variables, such as grain size, porosity, grain density and gas content that are directly related to the geological processes producing the wide range of sediments that are encountered in the world's oceans. A number of auxiliary technological objectives have also arisen in the course of our work related to remote sensing and in-situ measurement of sediment geoacoustic properties. One of these objectives has been to develop a set of tools that allow the measurement of velocity and attenuation as well as certain related geotechnical variables such as shear strength in the sediment column. These measurements provide the “ground truth” for assessing the validity and usefulness of the basic geoacoustic model.

APPROACH

My approach has been to develop a theoretical geoacoustic model based on the classical Biot theory for porous, fluid-filled media. The model reflects the influence of variables such as porosity and overburden pressure and includes several kinds of intrinsic attenuation that are important in different kinds of ocean sediment. We have performed extensive field and laboratory experiments aimed at determining appropriate input parameters as well as checking the validity of the model predictions. Much of our earlier work is described in the monograph "Sediment Acoustics" (Stoll, 1989). More recent progress, especially the results of extensive field work, has been described in a series of technical papers and is being incorporated into several new chapters in a second edition of the monograph to be published in the near future. Over the past several years we have participated in a number of field experiments in cooperation with other investigators such as T. Akal at SACLANT Undersea Research Center in LaSpezia, Italy and M. Richardson at the Naval Research Laboratory, Stennis Space Center. During this work several new testing techniques were developed to measure in-situ properties of the sediments immediately beneath the seafloor including shear wave velocity and attenuation for both vertically and

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horizontally polarized wave motion, and undrained shear strength based on quasistatic cone penetration tests. In addition, sediment cores taken at many sites were analyzed to obtain porosity, grain size distribution and other fundamental properties, the objective being to establish the ground truth at each test location and develop correlations between such quantities as in-situ shear wave velocity, undrained shear strength and porosity.

In addition to the field work mentioned above, a new series of laboratory experiments were begun with the purpose of studying the dispersion that occurs during p-wave propagation in granular sediments as one moves from the "low frequency" regime to the "high frequency" range that is currently of considerable interest. The purpose of this work is to help in the evaluation of some of the new propagation models that are being proposed to explain the penetration of acoustic energy into the seafloor at low grazing angles observed in recent experiments. Some of these new models that are based largely on high frequency data, and in some cases idealized scattering models, do not properly account for the dispersion that would normally be expected in going from low to high frequencies and therefore may be questionable for applications in the general case.

WORK COMPLETED

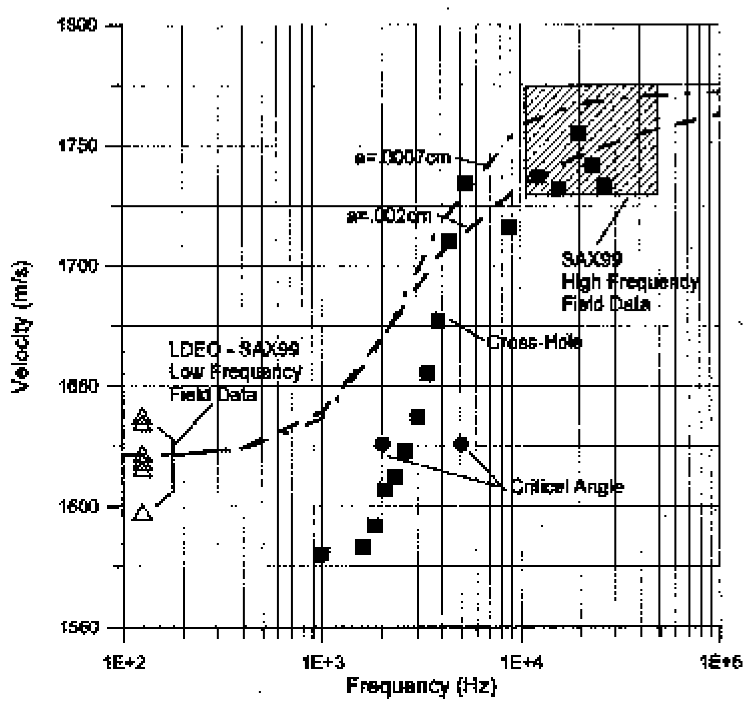
At the end of last year our research team, which includes R. Stoll and I. Bitte from Lamont-Doherty Observatory and R. Flood from the Marine Research Lab, SUNY, Stony Brook, carried out field experiments in the Gulf of Mexico near Ft. Walton Beach, Florida as part of the ONR SAX99 experimental program. These experiments which were part of the ONR High Frequency Acoustics DRI, were aimed at establishing a baseline model valid over a somewhat wider frequency range than the main high frequency experiments and to see if velocity dispersion as predicted by the Biot theory would play an important role in interpretation of the SAX99 experimental results. During the current fiscal year analysis of the data from this experiment has been largely completed and we have submitted a paper to the Journal of the Acoustical Society of America describing the results. In addition Stoll attended the ONR high frequency acoustics workshop in Lyon, France to present the results of our work.

In the lab, we have been modifying test equipment to allow more extensive acoustic testing of granular sediments in the low frequency range.

RESULTS

Analysis of our field data shows that there is pronounced velocity dispersion that occurs in uniform, unconsolidated sands in the intermediate frequency range (typically between 500 Hz and 10 kHz). This dispersion, which is one of the most striking predictions of the Biot theory, has important implications when interpreting bottom-penetrating sonar records (Maguer et al, 2000) as well as when choosing attenuation values for geoacoustic modeling purposes. Our results suggest that the historical method of cataloging attenuation as a single value valid at 1kHz and then assuming that the attenuation varies as (or nearly as) the first power of frequency can lead to poor estimates when extrapolating to a different frequency range. Moreover, our results also demonstrate that a linear viscoelastic model, based on an assumed relaxation function that leads to attenuation varying as the first power of frequency, is not adequate for describing the response of marine sediments such as unconsolidated sand.

Dispersion in Granular Sediments



Some experimental results that illustrate the extent and importance of the velocity dispersion are shown in the figure below. The data points labeled "cross hole" are based on work by Turgut and Yamamoto (1990) wherein direct measurements of velocity between a buried source and receivers were made in a beach sand. The labeled "critical angle" are based on critical angle measurements made by Maguer et al (2000) in clean sand near the Isle of Elba. High and Low frequency results from the SAX99 experiments are also shown together with preliminary dispersion curves calculated using the Biot theory.

IMPACT/APPLICATION

While our primary interest has been to model geoacoustic properties of the sediment, a number of tools developed for our field work have direct applications to other areas of interest to the Navy such as mine burial prediction. As an example, the penetration resistance measured by several different types of probe we have developed is directly related to the bearing capacity of the sediment which is of prime importance in studies of mine burial in the seafloor. These probes have been used to map critical areas in two recent NATO exercises aimed at 'Rapid Environmental Assessment'.

TRANSITIONS

We have prepared an XBP (expendable bottom penetrometer) evaluation package for the Naval Oceanographic Office composed of software, an electronics interface board and a users manual for use on board NAVO ships. As a result of their initial trials of the XBP they have ordered eight additional systems for use on their survey vessels.

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